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DESIGN OF IRRIGATION SYSTEMS

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IRRIGATION DIVISION

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AMERICAN SOCIETY OF CIVIL ENGINEERS
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PAPERS

DESIGN OF IRRIGATION SYSTEMS

By W. H. Nalder,[1] M. ASCE

Synopsis

An account of the planning and design considerations entering into the development of irrigation features of multiple-purpose projects of the Bureau of Reclamation (United States Department of the Interior (USBR)) is presented in this paper. Reviewed are the major factors affecting irrigation development and their attendant engineering implications, the elements of an irrigation system, and the influence of economics on design. Also the principal features of three reclamation multiple-purpose projects are discussed. The paper concludes with a brief discussion of irrigation's future importance in the over-all social and economic aspects of water and land resource development.

Introduction

This subject is so broad and so indefinite in its limits as to include almost any irrigation system from a simple structure diverting water from a stream into a canal and laterals (to provide irrigation of low-lying land along the stream) to a group of structures for river control and for utilization of the water resources of an entire river system. There is very little need to describe a simple irrigation project. Although such a widespread integrated system as the Missouri River Basin Project contains many individual units that are in themselves fairly complete, simple projects, most of the uncomplicated locations are utilized and the cheap developments have been constructed. In many places, water rights have been established and water demands exist that already exceed the readily available water supply. The irrigation engineer, therefore, must seek new sources of water such as the storage and the utilization of flood flows, the diversion from sources of lower demand, and the re-use of water from return flows.

Before he can apply his talents to the design of the works that comprise the irrigation features of a project, the irrigation engineer is required to coordinate a wide variety of demands for water or for its control. Even after agreement is

Note.—Written comments are invited for publication; the last discussion should be submitted by August 1, 1951.

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reached between various interests as to the diversion of the water, the manner in which the requirements are to be satisfied (in a structure which serves several purposes, or in multiple structures or units of a project operated according to a compromise plan) requires the services of a complex organization for planning, construction, operation, and administration of the system.

By its very nature, irrigation development is destined to become more complex as it progresses: Development of an area through irrigation fosters the development of the natural resources, land, mineral, and forest; settlement is encouraged, including the building of farms, cities, industries; the population increases, which requires food, and domestic water, power, and transportation facilities; demands for protection against floods and for conservation of resources develop; the people seek recreational facilities; and manifold influences are exerted on economic and political activities. All these factors are related to, and either are reconciled with, or are in conflict with, each other by the common denominator, the available water supply. The interrelated development necessarily depends for sustenance on the irrigation that gave birth to or nurtured the development and its demands for water cannot exceed the supply if it is to thrive.

Factors Affecting Irrigation Development

A few factors affecting irrigation development, and their engineering implications and effect on irrigation design, greatly simplified, are: Power, flood control, navigation, industrial and domestic demand, recreation, fish and wildlife, and political circumstances.

Power.—Development of water power, whether incidental to irrigation or of primary concern, imposes requirements for the utilization of head, equalization of flow, storage of water with attendant inundation of river valley lands, and use of water that in many instances conflicts with its use for irrigation. Power revenue, however, is the saving factor of many multiple-purpose projects. This factor makes the project economically feasible and helps to repay the cost that could not be borne entirely by the direct fruits of irrigation. In this way, power supports irrigation, which directly or indirectly sustains the demand for power. The two mutually supporting factors may thus become the base of the entire development.

Flood Control.—Encroachment on flood plains by agriculture, cities, industries, and service facilities such as utilities, roads, and railroads creates demand for protection against floods which requires storage of flood flows beyond channel capacity. Releases for flood-control purposes usually are not coincident with the demands of irrigation. The flood-control benefits of a project can be evaluated, and (since it is usual for the cost of flood control on reclamation projects to be borne by appropriation from nonreimbursable funds) charges allocated to irrigation development may thereby be reduced and the feasibility of the project enhanced.

Navigation.—In a section of a river system where irrigation and consumptive use of water are involved jointly with navigation, the maintenance of a fixed-depth channel for navigation imposes demands for the release of water that conflict with other uses. Navigation likewise imposes limitations on the height

of dams since the cost of providing navigation facilities over a high dam would usually make the project prohibitively expensive.

Industrial and Domestic Demand.—Domestic use of water usually takes precedence over all other uses. Water supply for communities served by irrigation is not generally so great as to constitute a serious depletion of the water available for irrigation, although certain industrial uses threaten (by demand for large quantities of water or by contamination of the water) to curtail irrigation development. For example, further transmountain diversion of Colorado River water for use in irrigating the eastern slope is opposed by certain western slope users who anticipate demand for large quantities of water for the development of the oil shale resources of western Colorado.

Recreation.—Irrigation reservoirs create potential resort and recreation areas which in turn present demands for the maintenance of a level of water or of a continuity of flow which is inimical to the most effective irrigation. There is a warranted and growing demand for the development of these recreational facilities. In some instances, national park areas and primitive areas would be the logical sites for irrigation reservoirs or dams, but they usually cannot be encroached upon for such purposes.

Fish and Wildlife.—The drainage or flooding of swampland that supports wild fowl, the construction of high dams that affect the movement of migratory fish, the changing of flow characteristics of a stream, and the cultural development of an area which may be associated with irrigation development but which affects the wildlife of a region—all may be stoutly resisted as being destructive in character and as usurping the rights of the commonwealth and of posterity.

Political Circumstances.—Not the least of the factors affecting irrigation development are conflicting jurisdictional claims of districts, states, and nations when the waters of a stream must be divided between them. Development for a certain purpose, in conflict with or to the exclusion of others, may also be dictated by legislative bodies or by courts; or the impetus of a particular development may be provided by political programs.

Planning the Multiple-Purpose Project

A plan is evolved which is usually the best compromise that can be worked out of the various factors and interests that are affected; and it passes through a series of steps designed to bring the project to completion. The complexity of the plan, the legislative authority required, the magnitude of the financial obligation, and the involvement of the interests of the whole community in any extensive irrigation scheme have caused irrigation development to be considered and generally accepted as a proper governmental function. The agency of the United States Government charged with this function is the USBR, and its counterpart exists in nearly every nation where irrigation is an important feature.

Although procedures vary considerably with circumstances, irrigation development may include the following steps. Community interest in irrigation for a certain area comes to the attention of the USBR. Then advance studies are made relating to its feasibility and to how best it can be fitted into a basin-wide plan embracing other adjacent or related areas and involving the best

over-all use of the available water supply. This plan will be likely to include storage reservoirs with incidental power development, flood control, and other benefits.

As authorization and funds are made available, more detailed surveys and studies are made—including location and investigation of reservoir and dam sites, road and railroad relocation, canal location, irrigable land surveys, and preliminary designs and estimates—and the project plan is developed which is coordinated with federal and state agencies where their interests are involved. Construction work is programmed, construction contracts are let, and construction is completed as circumstances warrant and as funds become available.

Irrigation Features of Multiple-Purpose Projects

The plan of a project, evolution of the plan, and features of design of an irrigation system may be indicated by presenting a detailed description of a particular project, emphasizing the irrigation features but presenting at the same time the related features of power development, flood control, and other

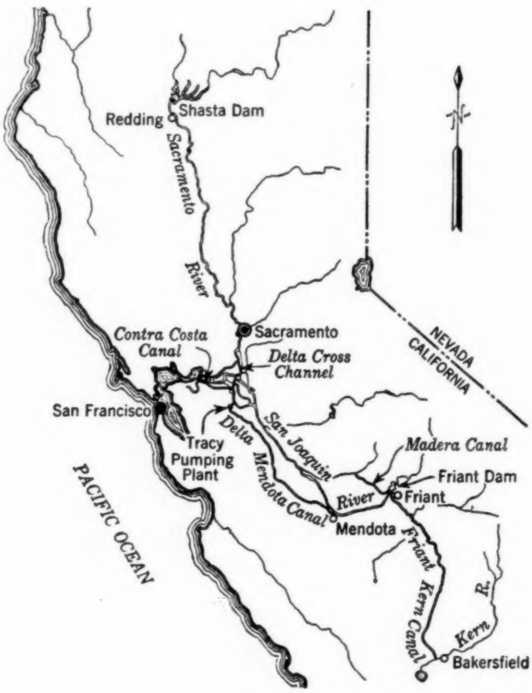

FIG. 1.—CENTRAL VALLEY PROJECT OF CALIFORNIA

incidental benefits. Choice of the project to be described is difficult in itself because, usually, a single project does not include all features that might be presented; or the project may be so complex that it is impossible to describe in a short presentation.

As an example in the latter category, one should mention the Central Valley Project of California (Fig. 1). The initial plan of this project, well advanced in construction (1950), includes: Two high concrete dams—the Shasta Dam on the Sacramento River to provide the main source of water and the Friant Dam on the San Joaquin River; irrigation of a large area in the upper San Joaquin River Basin; transfer of water from the Sacramento River to the San Joaquin River to satisfy established claims for water below the newly irrigated regions; power development; flood control; salinity control of the delta region at the confluence of the two rivers; provision for the care of migratory fish; extensive relocation of railroad and highways; and a number of other features that could not be omitted from an adequate description of the project.

This initial plan has been expanded to a plan for the complete and comprehensive development of the water resources of the Central Valley which contemplates the construction of numerous additional dams, power plants, and canal systems.

Columbia Basin Project

The most extensive compact irrigation project under construction by USBR is the Columbia Basin Project in the State of Washington. Fig. 2 shows a 426-mile canal system for carrying irrigation water to about one million acres—an area larger than the State of Rhode Island. The first major feature of the project to be constructed was the Grand Coulee Dam on the Columbia River, containing more than 10,000,000 cu yd of concrete, the largest in the world in point of volume. It is a straight gravity dam 550 ft high and 4,173 ft long.

The power development at Grand Coulee Dam has already become the world's largest capacity plant with eighteen of the largest generators in existence in operation or under contract for purchase and installation. Each unit is rated at 108,000 kva, but the units installed have been operating at about 15% overload capacity. The power plant is divided into two sections, one on each side of the spillway. At the inception of the project it was considered that the principal demand for power from the Grand Coulee Plant for many years would be to pump irrigation water from Lake Roosevelt to the Coulee Reservoir at the head of the irrigation system. During and since World War II, the industrial development of the northwest has expanded at a much more rapid rate than the power supply, and the power demand has been so heavy that construction and installation of the generating equipment have not been able to keep pace with the demand. This is an excellent example of the incidental benefits of an irrigation project becoming, for a while at least, the principal benefits. In this instance power development will repay the major cost of the project.

When Grand Coulee Dam was constructed, provision was made at the left abutment for the beginning of the canal system by building a gravity wing wall equipped with twelve, 13-ft by 20-ft hydraulically-operated gates to function as an intake structure to serve twelve pumps each capable of lifting 1,600 cu ft per sec up the 270-ft to 365-ft difference in elevation between Lake Roosevelt and the feeder canal leading to the Upper Coulee Reservoir. The pumps are driven by twelve 65,000-hp motors, two pumps serving as reserve units. The maximum demand can be supplied by ten pumps. Power to drive each set of two motors is derived from one of the 108,000-kva generators of the Grand

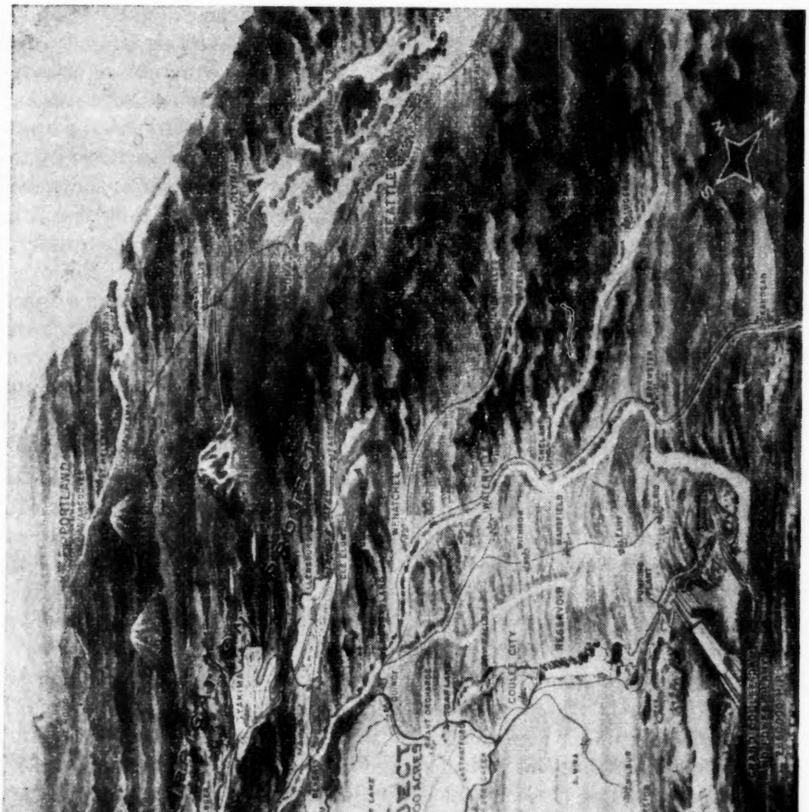
COLUMBIA
BASIN
PROJECT
PASCO
SPOKANE
PORTLAND
COULEE CITY
RESERVOIR

Fig. 2

Coulee Power Plant. Water is to be pumped during the hours of low power demand into the Grand Coulee Equalizing Reservoir which serves regulating storage for the irrigation system, from which water flows by gravity over most of the irrigated area. Six pumps are planned for initial installation, two of which are currently (1950) being installed for operation by May, 1951. The remaining four units are to be in operation by the spring of 1952.

Emanating from the pumping plant, are twelve steel discharge pipes, 12 ft in diameter, threaded through twelve inclined rock tunnels, each 18 ft in diameter. These discharge pipes terminate in a siphon structure at the head of the feeder canal. The feeder canal leading to the Upper Coulee Reservoir has a design capacity of 16,000 cu ft per sec. It is 1.6 miles long and open concrete lined except for 2,000 ft of double-barreled concrete conduit, 25 ft in diameter, traversing a slide area.

The equalizing reservoir utilizes the Grand Coulee, which was the channel of the Columbia River thousands of years ago. The reservoir with a capacity of 1,200,000 acre-ft is formed by construction of an earth dam at each end of the 26-mile long coulee. The North Coulee Dam is rather small in comparison with its companion, the South Coulee Dam, which is 2 miles long and 115 ft high at the maximum section.

The headworks of the Main Canal are located at the South Coulee Dam, and they house a battery of six 12-ft by 18-ft radial gates to control the release of as much as 13,200 cu ft per sec of irrigation water. The first leg of the Main Canal is 11 miles long and has one 23.25-ft diameter, 1,000-ft long siphon and one equivalent size horse shoe, concrete lined tunnel, 1,000 ft long. An additional siphon and tunnel of the same capacity and dimensions is planned for future construction. After diverting water into the East High Line Canal, the first leg of the Main Canal will terminate by cascading water over a 165-ft natural rock drop into Long Lake. When completed, the 110-mile East High Line Canal will have a maximum capacity of 3,070 cu ft per sec to serve 215,000 acres of land.

Long Lake is increased in size by the construction of the 100-ft-high earth-fill Long Lake Dam and will supply the lower leg of the Main Canal with 9,700 cu ft per sec of water. An open type of headworks, containing three 25-ft by 25-ft radial gates, services the Main Canal which is 6.6 miles long. The lower leg of the Main Canal divides into two canals known as the East Low Canal and the West Canal, having capacities of 4,500 cu ft per sec and 5,100 cu ft per sec, respectively. The East Low Canal is the longest canal in the system and will traverse the entire length of the project for 137 miles to irrigate 252,000 acres. One tunnel and numerous siphons will be required.

The West Canal is 78 miles long and will eventually irrigate 281,000 acres of land, with gravity and pump laterals. The most notable structure in the West Canal will be the Soap Lake Siphon, a steel-lined, concrete pipe siphon, 2.5 miles long and 25 ft in diameter. Now under construction (1950) are 30 miles of the West Canal including four siphons, a wasteway, two pumping plants, and a three-main-line railroad crossing. The West Canal divides into two canals after passing through a tunnel, 9,150 ft long, under the Frenchman Hills.

Potholes Reservoir will recapture an anticipated 862,000 acre-ft of return flow from the irrigated lands above the reservoir. Augmented by water from

the wasteways of the East Low and West canals, storage in the reservoir will be retained behind the earth-fill, O'Sullivan Dam, which is 3.5 miles long. At some future time it is planned to use the reservoir to service the Potholes West Canal, 22 miles long, with 235 cu ft per sec, to irrigate 13,600 acres, as well as the Potholes East Canal, 60 miles long, with 3,900 cu ft per sec to irrigate 254,000 acres of land.

Several pumping plants served by the West Canal will lift water to irrigate an additional 13,000 acres of excellent quality land.

Republican River Basin

Development of the Republican River Basin, in Colorado, Kansas, and Nebraska, is a part of the integrated development of the Missouri River Basin Project, many units and features of which are now (1950) under construction by the USBR and the Corps of Engineers, United States Department of the Army. The Republican River Valley is typical of many reclamation projects in the Great Plains area and serves as a good example of how the objectives of flood control and irrigation may be achieved by coordinated development. Unlike the single large compact development characterized by the Columbia Basin Project lands, the Republican River Basin irrigable lands are scattered along the flood plains of the rivers for more than 300 miles and comprise sixteen separate irrigation units in three states. The operation of these units must be closely coordinated and timed to produce the maximum possible utilization of available water supply and at the same time to assure protection from damaging floods.

The Republican River rises in northeastern Colorado about 100 miles east of Denver. It flows through the northwestern corner of Kansas and then into Nebraska where its course follows an easterly direction along the southern border of that state. From Nebraska the river turns southeast, emptying into the Kansas River at Junction City, Kans. The drainage basin of the Republican River is approximately 425 miles long and is about 125 miles wide at the widest place. The basin has an area of 26,500 sq miles and the total drop in elevation is 3,000 ft.

Irrigation in the basin in the past has consisted principally of private developments serving about 20,000 acres. Ultimate development anticipates irrigation of about 165,000 acres of new land and provision for an additional supply of water to the lands now under irrigation.

A map of the Republican River Basin is shown in Fig. 3. The works to be constructed in the basin to serve the sixteen separate irrigation units, according to present plans, are fourteen storage dams, eight diversion dams, and about 300 miles of new canal; and several existing diversion dams and numerous stretches of existing canals are to be rehabilitated. Because of the runoff characteristics of the entire area, the control of floods is an important and controlling factor in designing the storage dams and in providing for passing high flows at the diversion structures.

The maximum flood of record on the Republican River occurred in 1935 when a peak flow of about 265,000 cu ft per sec was reached, and loss of human life and extensive property damage resulted. Hydrologists estimate that this was of the order of a 1,000-year flood for the river. The impact of such a flood may be better appreciated in light of the fact that the average annual discharge

is only 740 cu ft per sec. The dams being constructed on the Republican River and its tributaries are provided with spillways that might be considered disproportionately large without full consideration of the flood potentialities of the basin. The storage reservoirs, which will have a combined total capacity of 1,786,000 acre-ft, will have more than 1,000,000 acre-ft of this capacity allocated to flood storage, leaving only about one third of the total capacity available for irrigation storage. Table 1 shows the storage dams required for the development, and their respective capacities.

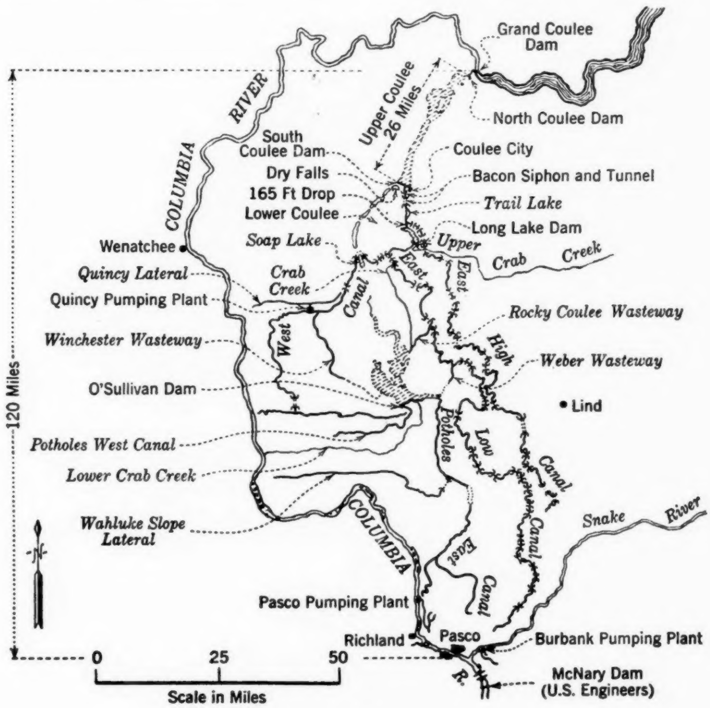

Fig. 3

Somewhat typical of the storage dams in the Republican River Basin is the Medicine Creek Dam located on that creek some 10 miles above its confluence with the Republican River.

This dam, of the zoned earth-fill type, has a maximum height of about 115 ft above the stream bed, and the 30-ft base-width cutoff trench excavated 60 ft upstream from the axis, extends about 50 ft below the stream bed to a shale and chalk formation. The dam is approximately 5,600 ft long at the crest, which has a width of 30 ft. The total volume of all classes of material in the embankment is 2,676,000 cu yd.

The outlet works along the right abutment consist of a vertical shaft inlet, a horseshoe conduit (8 ft in diameter) from there to the gate chamber, and an identical conduit from the gate chamber to the control house. An hydraulically-operated slide gate, 3.25 ft square, is installed in the gate chamber

from which a steel outlet pipe (44 in. in diameter) installed in the conduit leads to another identical slide gate in the control house. Discharge is into a concrete stilling pool. The spillway designed for a maximum discharge of 139,000 cu ft per sec is an open channel through the left abutment. In downstream order it consists of an uncontrolled crest, a channel, and a stilling basin—all of concrete. About 32,000 cu yd of concrete is placed in the outlet and spillway structures. The storage dams completed or under construction in 1950 are shown as items 4, 5, 6, 8, and 12, Table 1.

Operation of the storage and diversion facilities will require the development of a master plan for the coordinated control of the entire flow of the river and all its tributaries. Because of the erratic runoff characteristics of the entire area,

TABLE 1.—STORAGE DAMS REQUIRED FOR THE DEVELOPMENT OF THE REPUBLICAN RIVER IN COLORADO, KANSAS, AND NEBRASKA

Line No.	Reservoirs	Approximate height, in feet	Crest length, in feet	Total embankment, in cubic yards	Acre-Feet		
					Irrigation	Flood control	Ultimate
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	Wray	....	....	....	6,000	1,000	7,000
2	Pioneer (USCE)[a]	....	....	....	28,000	73,000	101,000
3	Rock Creek	....	....	....	10,500	....	10,500
4	Bonny[b]	130	9,300	9,207,000	43,000	132,000	175,000
5	Trenton[b]	100	8,600	7,800,000	122,820	133,760	256,580
6	Enders[b]	100	2,600	1,895,000	44,000	30,000	74,000
7	Red Willow (USCE)[a]	....	....	....	18,400	22,000	40,400
8	Medicine Creek[b]	115	5,600	2,700,000	40,000	53,000	93,000
9	Beaver City	....	....	....	21,000	20,000	41,000
10	Oberlin	....	....	....	18,000	20,000	38,000
11	Norton	....	....	....	19,000	20,000	39,000
12	Harlan County (USCE)[a,c]	100	11,000	10,714,000	350,000	500,000	850,000
13	Thompson Creek	....	....	....	13,800	10,000	23,800
14	Lovewell	....	....	....	25,000	12,000	37,000
15	Totals	....	....	....	759,520	1,026,760	1,786,280

[a] Corps of Engineers, United States Department of the Army. [b] Earth-fill dam. [c] Earth and concrete dam.

it will be necessary to make adjustments in storage from one reservoir to another to insure flood protection at all points and, at the same time, to leave adequate water storage for late season irrigation demands. On a river development of this magnitude, the practice of irrigation over a period of years is certain to bring about substantial amounts of return flow. By proper handling of the various storage facilities, much of this return flow may be re-used to advantage.

ELEMENTS OF AN IRRIGATION SYSTEM

From the foregoing examples, and from consideration of the function of an irrigation system, the structural elements of a system may be visualized. The diversity of forms and the complexity of arrangements make impossible the complete listing of all elements and their design considerations in a short paper. Generalized elements may be considered in terms of: Storage reservoirs, diversion and headworks, conveyance structures, regulating structures, protection structures, and drainage systems.

Storage Reservoirs.—Formed by dams of all types, storage reservoirs usually serve as the source of supply, sometimes to supplement normal low-water flow. These dams have extensive control structures such as spillways and outlet works.

Diversion and Headworks.—Diversion and headworks may take the form of a diversion dam of any type, with headworks or a pumping plant if the source of water is a flowing stream. Control structures at the headworks are sluice and gate arrangements with auxiliaries as required, such as stop-log provision, trashracks, and fish protection.

Conveyance Structures.—Canal lines from the large main canal at the headworks to the small branch laterals and ditches which serve individual farms, with special structures inserted in the lines as required, present many types of engineering problems and all possible combinations of forms. Structures of steel or concrete and (in some instances) wood, include siphons, flumes, conduits, culverts, chutes, drops, and transitions. Tunnels are frequently required. Canals may be unlined or lined (to prevent seepage or erosion) with a variety of materials including concrete, clay or bentonite, asphalt, and rock. Special conveyance methods such as pipe distribution systems or sprinkler systems may be used. Very extensive underground pipe systems are being built by the USBR for the first time in California.

Regulating Structures.—Checks, orifice structures, Parshall flumes, turnouts, vane and venturi meters, and weir structures of many types may be used to control and measure the flow as desired.

Protection Structures.—Culverts, drain inlets, overchutes, spillways, and wasteways are incorporated in the system as required to prevent interference of natural drainage with the irrigation system or to remove surplus water from a section of the canal line without damage to the system.

Drainage Systems.—Removal of excess water from the surface or from the subsoils may be as important to the irrigation system as the conveyance and the distribution of water to the land. Surface drains or subsoil drains may be open ditches or tile drains; or water may be drained by pumping.

Influence of Economics on Design

The trend of irrigation development is toward larger systems, requiring larger headworks and larger main canal lines and structures than were feasible only a relatively short time ago. Use of heavy mechanical equipment that can handle large quantities of materials cheaply has been the principal contributing factor to this trend. Mechanized canal excavation and trimming, lining, and finishing equipment permit large canals to be constructed quickly and at low unit cost, and in turn require large systems and long sections of canal to justify their use economically.

Heavy earth-moving machinery has been effective in completely reversing the trend of the unit cost for moving earth as compared with the unit cost for other construction work so that large earth structures such as canal embankments and earth dams can be constructed at lower costs than their counterparts using other materials. Knowledge of soil mechanics, utilizing the earth materials at hand to the best advantage through improved design and construction procedures, and recognition of the possibilities and limitations of earth structures for hydraulic purposes have contributed to the safe construction of large,

economical earth structures, particularly of high earth dams. In the case of dams there is the further consideration that dam sites must be utilized which are not suitable for supporting concrete dams but which are, or can be made, suitable for an earth dam with its wide base. Most of the dams that are a part of irrigation systems, except storage dams in mountainous country, are earth dams and the proportion of earth dams will probably increase.

With the existing heavy demand on water, it is important that full utilization be made of the water allocated to irrigation and that loss through seepage from canals be kept at a minimum. On the other hand, it may be prohibitively expensive to line all canals by conventional methods. Considerable research and experimentation have been devoted toward the development of a low-cost canal lining. In this category is included a subgrade-guided slip form for placing concrete. This is used on smaller ditches to place concrete lining about 1.5 in. thick without using rails for supporting the slip form.

One of the most promising low-cost canal linings developed by the USBR is the buried asphalt membrane. The canal is excavated about 18 in. outside the finish lines and the membrane is applied by spraying hot asphalt on the excavated section using 1.5 gal per sq yd which produces a membrane nearly 0.25 in. thick. A satisfactory membrane can be formed with semiblown asphalt although catalytically-blown asphalt is preferred. The membrane is then covered with an 18-in. thickness of earth and gravel to prevent erosion of the protective cover. Trial installations indicate that buried asphalt membrane can be applied at a fraction of the cost of concrete lining.

The great cost of developing large irrigation systems generally indicates that the water users cannot repay the entire cost of the project from primary irrigation benefits alone. Multiple-purpose projects which provide power revenue and nonreimbursable benefits such as flood control, recreation, and fish and wildlife, then become the only feasible basis for developing the water, land, and the other natural resources of a region.

The Future of Irrigation

Irrigation development in the United States, as well as in more densely populated countries, will undoubtedly be relied on as the chief replacement of marginal lands removed from cultivation and as the source of supply of food for millions who reside in the semiarid regions. With virtually no new land to be opened for development except that which may be made fruitful through irrigation, the 20,000,000 additional acres that might be irrigated with the complete utilization of all the remaining water resources of the western half of the United States constitutes the last frontier that might be developed against the dwindling ratio of cultivated acres to population. Irrigation engineering, therefore, may become of greater importance in the foreseeable future than in the past, but it will not be irrigation engineering by itself. The design of irrigation systems will be linked with the design of facilities to utilize all the water available in the most effective manner for the greatest benefit of all, in larger, more extensive, and more complex multiple-purpose projects or basin developments than have yet been constructed.

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